Changes in room acoustics engage spatial sound processing: an MMN study

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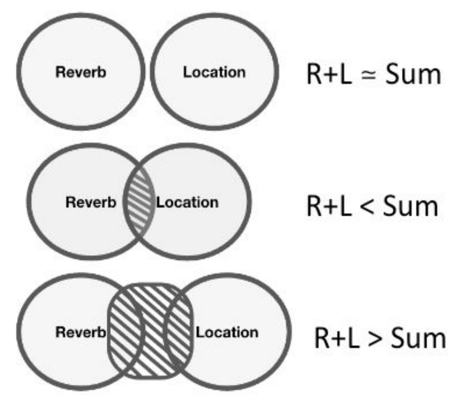
Introduction

- People experience sounds in many different spaces.
- Both changes in room size [1] and sound source location [2] have been shown to elicit MMN.
- Previous research does not yet clarify whether these processes engage **overlapping** or completely **separate** neural resources.



RESEARCH QUESTIONS

1. Do we detect changes in room size and sound source location pre-attentively?
2. Do these processes share resources in the brain or function independently?
3. Which areas of the brain do these processes engage?
4. Does the frequency of the sound stimulus affect neural activity?

Methods

- We used an **abstract MMN** oddball paradigm
- 3 deviant sounds presented at 8.3%.
- **All sounds were randomly intensity-varied (20dB, -15dB, or -12dB)** to prevent sound intensity change acting as a cue for deviant stimulus detection in reverberant conditions.
- We included **2 behavioral tasks** post-eeg recording.

STIMULI

- 250ms complex tones with 20ms fade in/out created in a ChucK-based program.
- Localization and reverberation added using *TuneIn Ear Test Software*.
    - 2m away, 1m above the ground, standardized Head-related transfer function (HRTF).
- Post-processing in *Audacity* into 1 second segments.
- Impulse responses of a Recording Studio and Bing Concert Hall (Stanford University) were used to simulate virtual acoustics.

Design

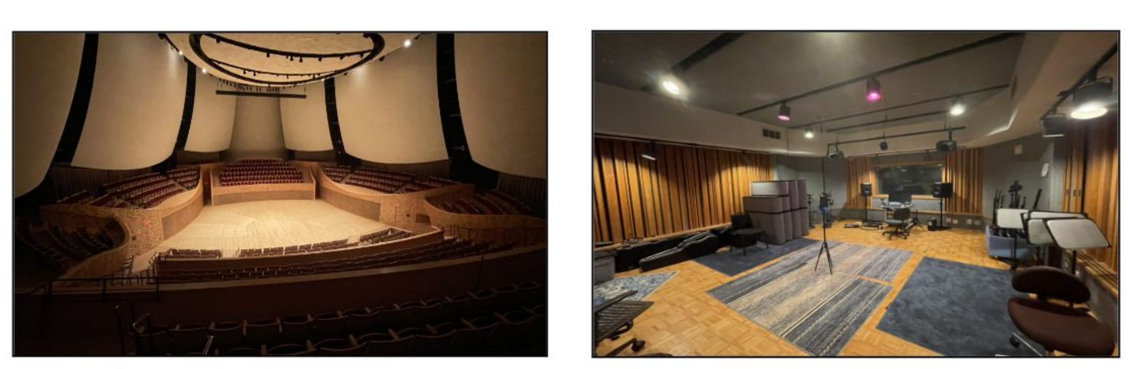
STANDARDS

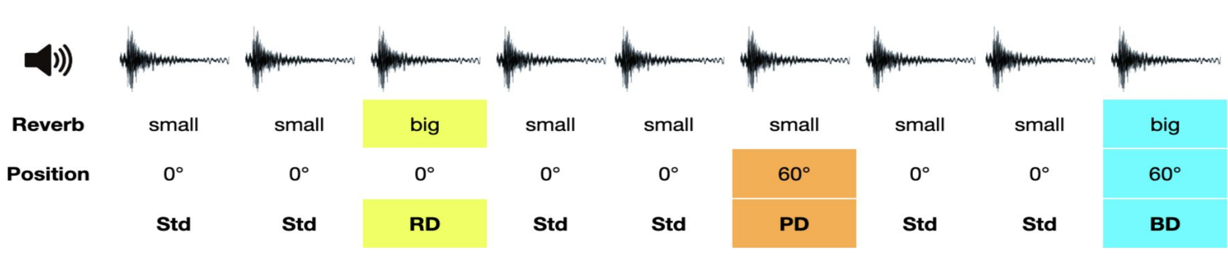
- Low (300 Hz) or High (2000 Hz) frequency
- Small or Big room (virtual acoustics)
- Originating from 0° front-center

DEVIANTS

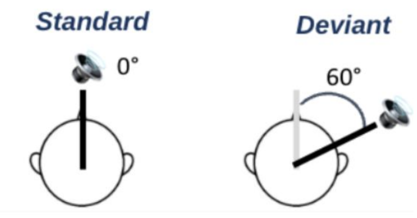
- Position (60° to the Right)
- Reverberation (Big or Small)
- Both Deviant (Position and Reverb)

Reverberation





Position



Procedures

PARTICIPANTS

21 adult volunteers (11 male, 9 female, 1 other; 6 Right-handed; Age: *M*= 30.86, *SD* = 8.06)
- 3 had no musical training, the rest had an average of 15.44 years of training (*SD* = 6.32)

EEG RECORDINGS

- Neuroscan SymAmpRT with whole-head 64-channel Neuroscan Quik-Cap (10-20 system).
- Recordings conducted in a sound-attenuated and electrically shielded room.
- Audio stimuli delivered through insert stereo earphones.
- 8 blocks total (1 second sound + 100ms IOI x 600 trials = 11 minutes per block).
- Block order randomly shuffled for each participant.

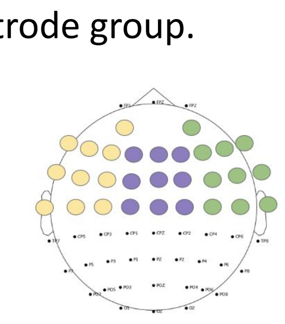
BEHAVIORAL TESTS

- Participants completed a PsychoPy experiment on a laptop while wearing over-ear headphones.
- Participants were presented the same stimuli as before and were asked to say whether sounds were:
    - coming from the front or to the right (location task)
    - in a big or a small room (reverb task)

Analysis

- EEG **epochs** (-0.2 to 0.8s) for stimulus onsets at 0s with DC offset correction (-.2-0s).
- Channels exceeding ±70µv were discarded.
- ERPs obtained for each condition and difference waveforms were obtained for each Deviant ERP type by subtracting the Standard ERP.
- Amplitude for MMN and P3a were calculated using the **time windows** (MMN:0.07 - 0.14s; P3a: 0.14 - 0.32s) determined by halfway points of the peak-to-peak amplitudes.
- Repeated-measures ANOVA with within-subject-factors Tone, Deviant type, and Electrode group.

- **Electrode groupings:**
    - FCL - Frontocentral Left (AF3, F7, F5, F3, FT7, FC5, FC3, T7, C5, C3)
    - FCM - Frontocentral Middle (F1, Fz, F2, FC1, FCz, FC2, C1, Cz, C2)
    - FCR - Frontocentral Right (AF4, F4, F6, F8, FC4, FC6, FT8, C4, C6, T8)



Behavioral data were analyzed by looking at correct answers and reaction time for each deviant type.

Behavioral Results

Correct Responses per Condition

Participants were most accurate in identifying room size of 300 Hz tones and least accurate for high frequency room size trials

Reaction Times per Condition

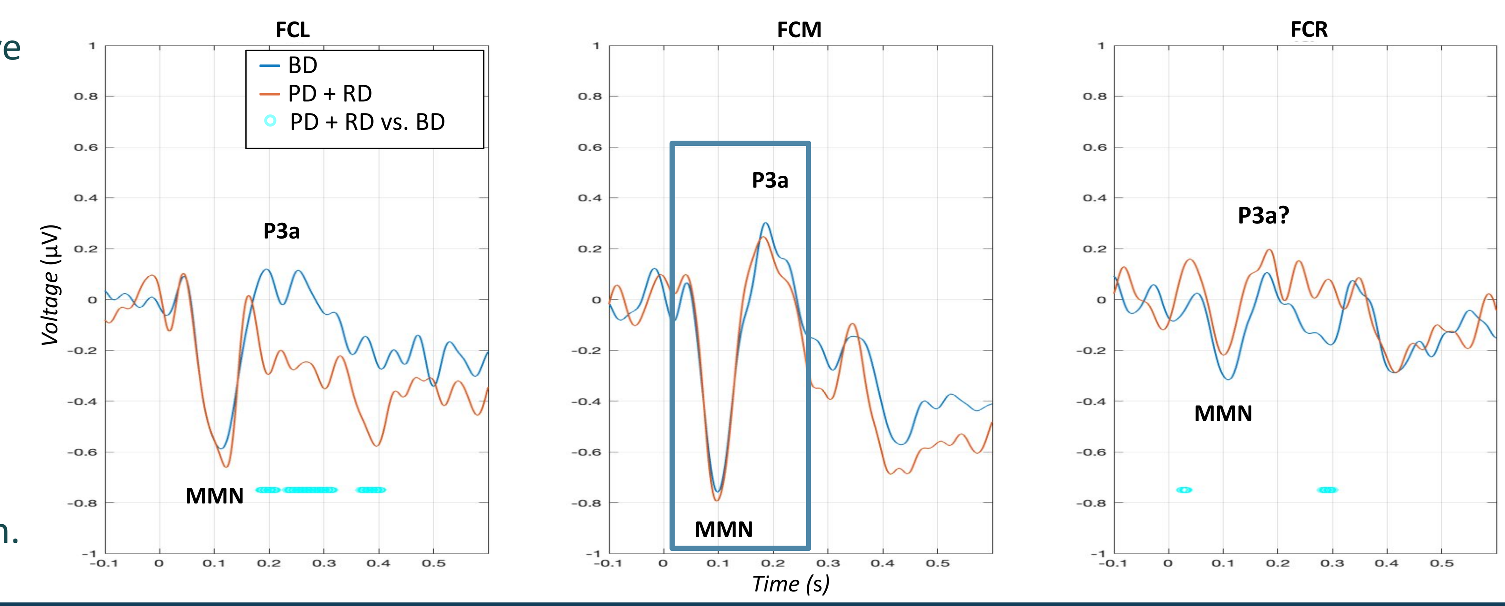
Reaction times were much shorter for the location task compared to the reverb task. Longer reaction times did not increase accuracy.

EEG Results

Both Deviant vs. Summation

The P3a (~200-400ms) for the Both condition shows larger amplitudes in the Front-central Left electrodes than the summation of the position and reverb deviant conditions.

Higher-order cognitive processing (**P3a** - involuntary attention orientation and memory update) is affected by **reverberation** as a result of sound localization contralateral to the stimulus presentation.

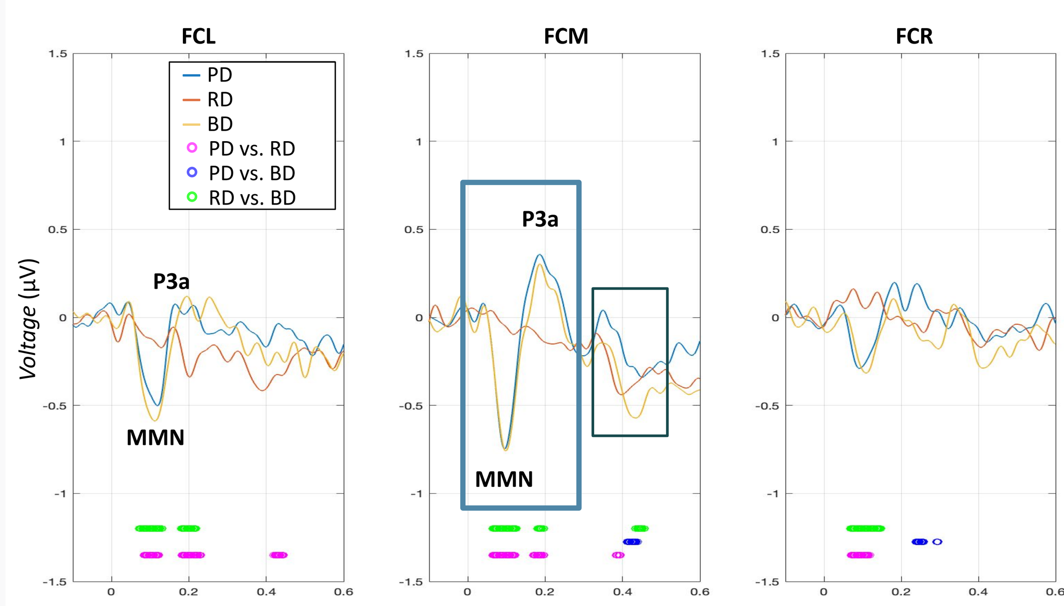


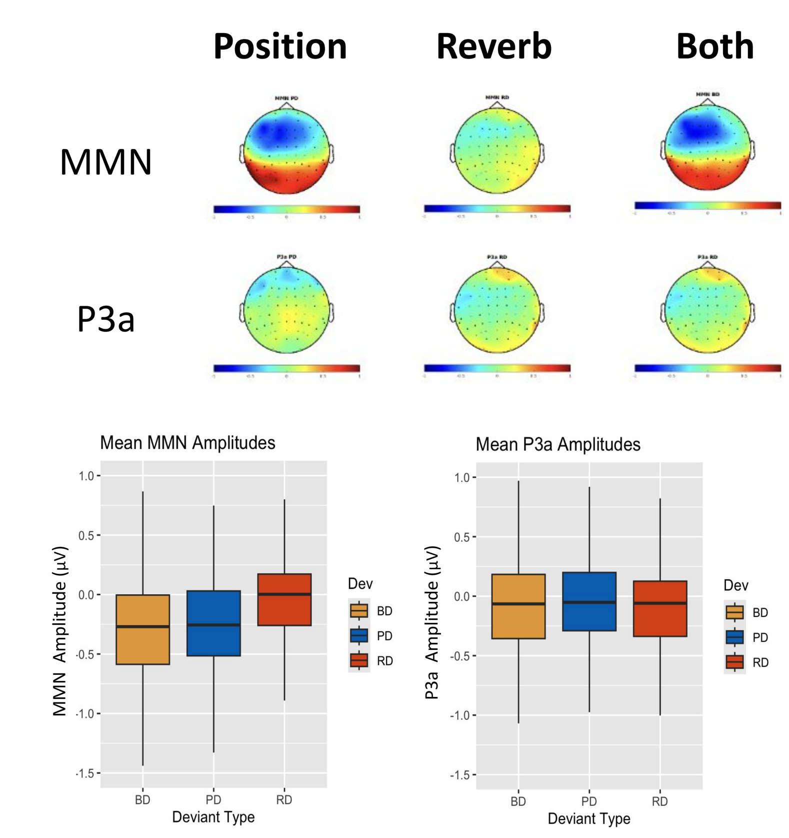
Enhanced contralateral processing of sound location in the presence of reverberation involves attention orientation, indexed by P3a.

Comparing the three deviant types

The MMN (~150ms) and P3a (200-400ms) are largest in the FCM electrodes, followed by FCL and FCR for all deviant types. This indicates the left-lateralized auditory cortical activities.

The MMN and P3a responses for the Position deviant and Both deviant conditions are similar and markedly larger than those for the Reverb deviant conditions.





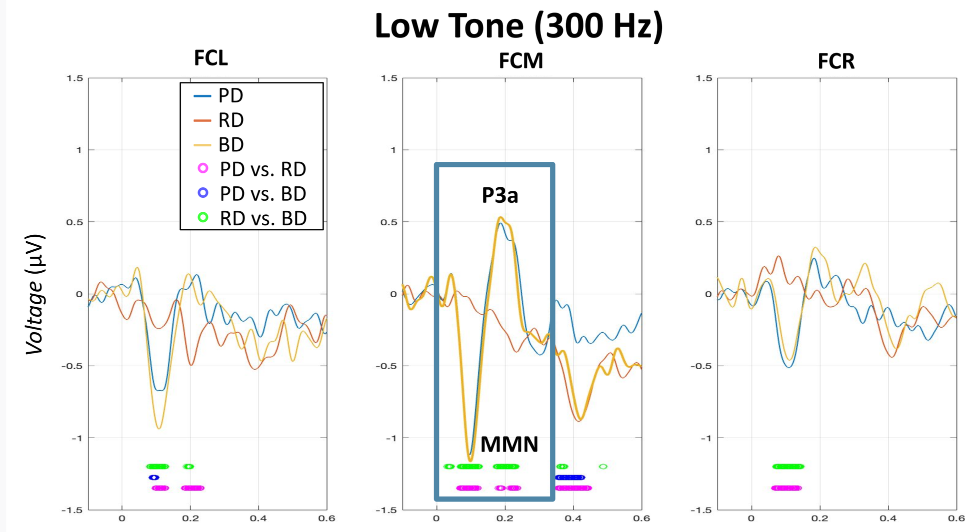
This implies that a change in reverberation alone does not engage the same level of resources as when a sound's location changes, regardless of reverberation change.

Sound location and reverberation information engage independent processes in the brain for the early pre-attentive change detection, indexed by MMN.

Comparing the two tone frequencies

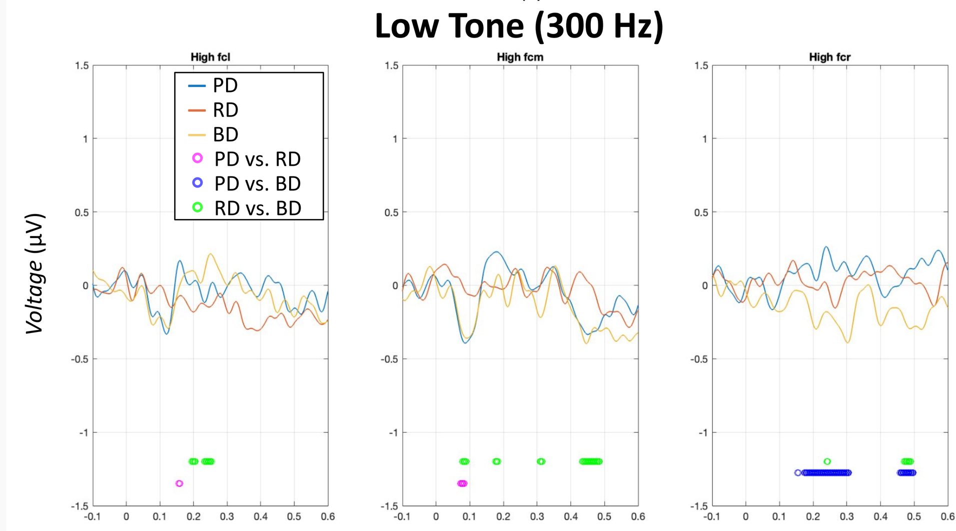
The MMN and P3a components were much larger in the low tone (300 Hz) conditions than in the high tone (2000 Hz) conditions, specifically in the FCM- followed by the FCL-electrodes.

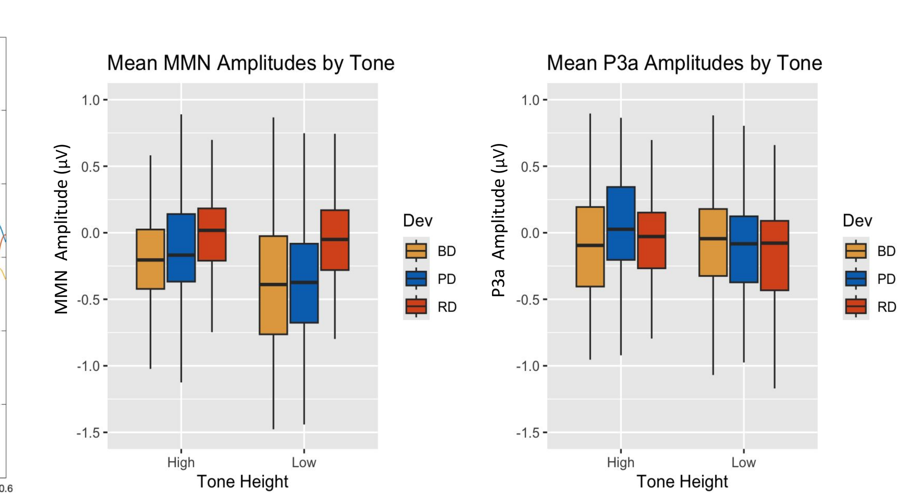
Low Tone (300 Hz)



The bigger responses for the low tone may be related to enhanced sound localization using Interaural Time Difference (ITD) in the presence of reverberation, and/or attenuation of the harmonics present in the high frequency tone typically involving Interaural Level Difference (ILD).

Low Tone (300 Hz)





For the low tone, the negativity around 400ms at FCM for the RD and BD conditions could potentially be an N1 response to the acoustic amplitude increase caused by the first reflections of the spaces.

Discussion

- Reverberation affects sound localization process for involuntary attention orienting.
- Higher order processing of reverberation and sound location **engage separate resources**.
- The fundamental frequency of the stimulus affects both attentive and pre-attentive responses when in the presence of reverberation or change in sound source location.
- Auditory spatial perception is affected by **room size**, sound location, and fundamental frequency.

References

[1] Weinzierl S., Lepa S., Thiering M. (2020) the language of rooms: from perception to cognition to aesthetic judgment. In: Blauert J., Braasch J. (eds) The Technology of Binaural Understanding. Modern Acoustics and Signal Processing. Springer, Cham.
[2] Kaplanis, N., Velzen, J. (2012). spatial perception in real-life acoustics: a study of perceptual auditory information of reverberation and its effect on space perception in musicians and non-musicians. Master's thesis, Doi: 10.13140/RG.2.2.16980.86404.
[3] Voss, P. (2016). auditory spatial perception without vision. Frontiers in Psychology, 7, 1960.
[4] Zahorik P. (2021) spatial hearing in rooms and effects of reverberation. In: Litovsky R.Y., Goupell M.J., Fay R.R., Popper A.N. (eds). Binaural Hearing. Springer Handbook of Auditory Research, vol 73. Springer, Cham.

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